Mucool Test Area

Cryo-system Design

BD/Cryo Internal Review

Part IV

Overview of the need for Liquid Hydrogen

Ch. Darve

Objective for Muon Cooling Experiment (MuCool):

Development of high intense muon source based on the phase rotation and muon cooling:

- ✓ High Intensity:1-2x10^{12}muons/sec
- ✓ High Luminosity:Improve beam emittance

Principle of beam optic

$$s_x = \sqrt{\frac{e_n b_x}{g}}$$

$$\frac{de_n}{ds} = -\frac{1}{b^2}\frac{dE_m}{ds}\frac{e_n}{E_m} + \frac{1}{b^3}\frac{b_\perp (0.014)^2}{2E_m m_m L_R}$$

Principle of ionization cooling

Bethe-Bloch

$$\frac{dE}{dx} = s\,\frac{Z}{A} \times z^2 \times f(g)$$

$\boxed{\text{6 W/cm}}$

Why do we use LH_2 and Aluminum?

Reference: Appendix by Robert Bernstein: "Failure-mode Metrology using Projected Target Videogrammetry", by John A. Greenwood et al., Coordinate Measurement Systems Committee conference in Albuquerque - (08/2001)

"The choice of absorber and window thickness is governed by a tradeoff between the energy loss and multiple Coulomb scattering in a material. The beam is "cooled" by energy loss; both transverse and longitudinal momentum is lost to collisions with atomic electrons but the longitudinal momentum is restored by the RF acceleration between the absorbers. Energy loss occurs when the muons in the beam electro magnetically interact with the electrons of the material and is governed by the Bethe-Bloch equation:

$$\frac{dE}{dx} = \frac{4N_o z^2 a^2}{mv^2} \frac{Z}{A} \left\{ \ln\left[\frac{2mv^2}{I(1-b^2)} \right] - b^2 \right\}$$

Where m is the electron mass, z is the charge (in units of the electron charge) and v the velocity of the particle, $\beta = v/c$, N_o is Avogadro's number, Z and A are the atomic number and mass of the material, and α is the electromagnetic fine-structure constant. The path length in the material, x, is measured in gm/cm^2. The quantity I is an effective ionization potential of magnitude $I = 10\ Z$ eV. The dependence of dE/dx on material is weak since Z/A is roughly 1/2 for all materials except hydrogen. Numerically dE/dx is 1–1.5 MeV $cm^2\ gm^{-1}$ and one multiplies by the density to find dE/dx in units of MeV/cm. The relevant point for this discussion is that dE/dx depends on Z/A"

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Part IV – A look at the Windows and Absorber Vessel

Overview of the need for Liquid Hydrogen

"Unfortunately as the beam traverses the material multiple Coulomb scattering increases the beam's phase space. Multiple Coulomb scattering represents the scattering of the incident particle on the atomic nuclei. The root-mean-square angular deflection in a thickness of material *x* is given by the approximate formula

$$q_{RMS} = \frac{21MeV}{pc}\sqrt{\frac{X}{X_o}}$$

where X_o, the "radiation length," is given by

and note the leading Z^2 dependence; hence as Z increases the scattering grows as Z^2.

We then see

$$\frac{1}{X_o} = 4Z^2 \frac{N_o}{A} a^3 \left(\frac{(h/2p)c}{mc^2}\right)^2 \ln\left[\frac{183}{Z^{1/3}}\right]$$

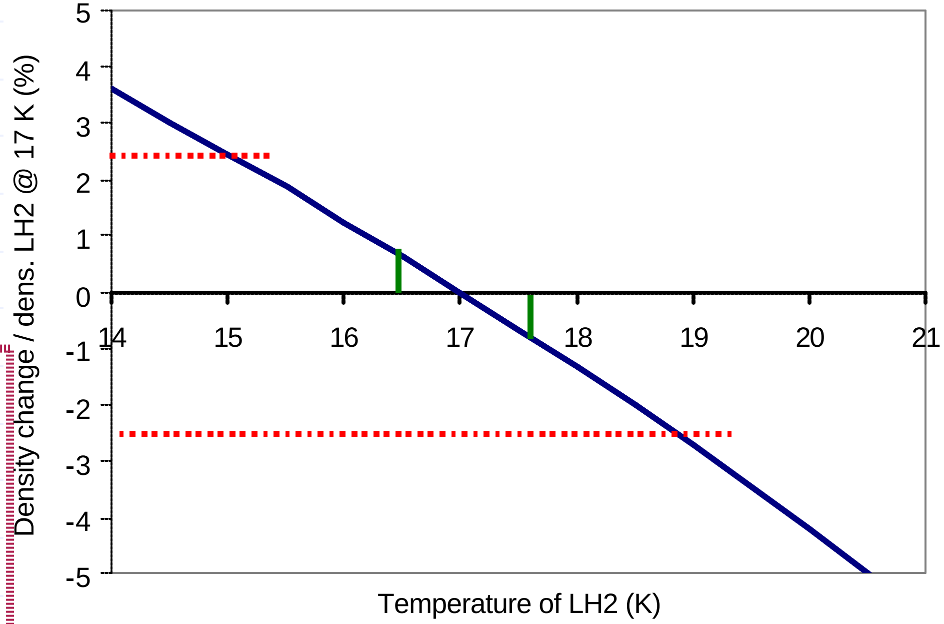
and therefore the best choice is the lowest Z material, hydrogen.

$$\frac{\text{Degredation from Scattering}}{\text{Improvement from dE/dx}} \propto Z$$

We would therefore expect the correct choice for window material would be Beryllium. However Be is known to be highly toxic if inhaled, leading to Beryllisois, a disease of the lungs. Proximity of a fragile Be window to a liquid hydrogen target is therefore too dangerous to consider and Aluminum is therefore the material of choice."

Main requirements for the cryo-system:

- ✓ Density fluctuation in the LH2 should be smaller than +/- 2.5 %
- ✓ P=1.2 atm=17.6 psia=0.12 MPa
- ✓ Subcool temperature => 17 K



1- Stay bellow boiling point

2- Temperature difference < 1 K

(using a large safety factor)

- in absorber volume

- in the cryo-system

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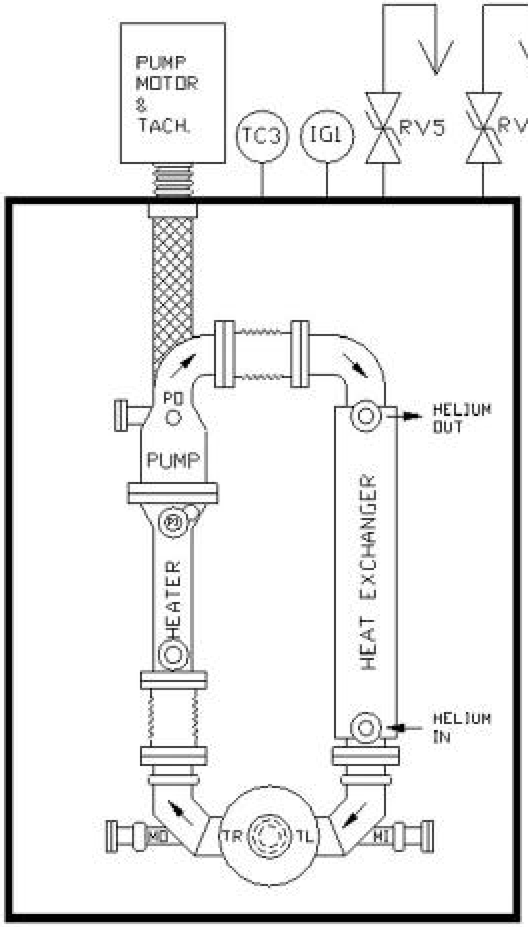
Overview on the Absorber Pump flow method

The LH_2 pump was designed and built by Caltech as a spare pump for the SAMPLE experiment (½ dia. of the pump used in E158)

Purpose:

To circulate LH_2 in a close loop and provide force flow to remove the energy loss from the LH2 absorber, with $\Delta T<1$ K

Schematic of SAMPLE



Reference:

"E.J. Beise et al., A high power liquid hydrogen target for parity violation experiments, Research instruments & methods in physics research (1996), 383-391"

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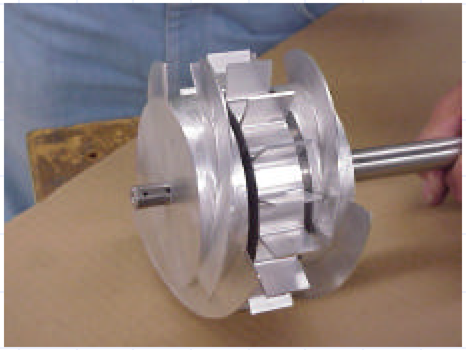
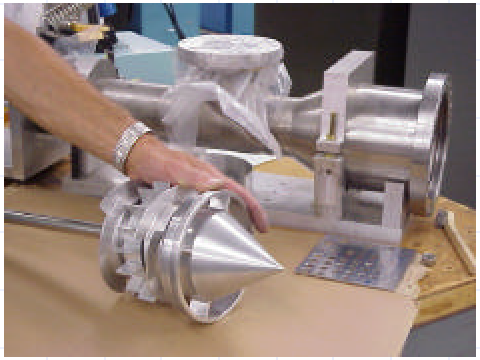
Overview on the Absorber Pump flow method



The LH_2 pump is composed of:

⇒ two impeller blades => to straighten the flow
⇒ three stators => to accelerate the flow
⇒ two cones => to reduce the impedance of the flow

Materials:
Impellers: Aluminum 6061 T6
Housing: 304



A motor located at room temperature drive the pump:
⇒ typical Tevatron Wet Engine 2 HP motor will be used

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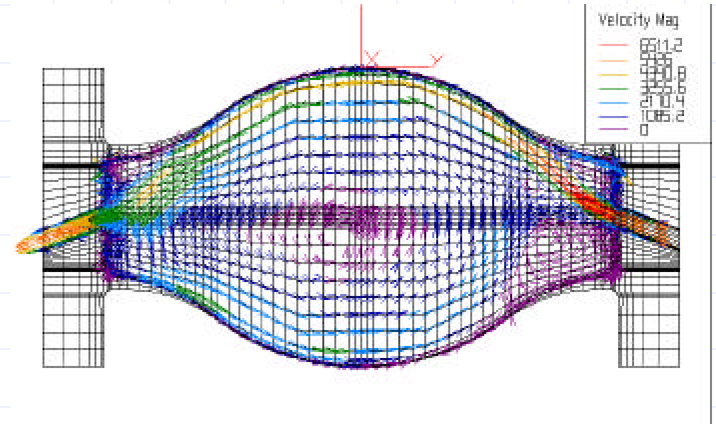
Overview on the Absorber Pump flow method

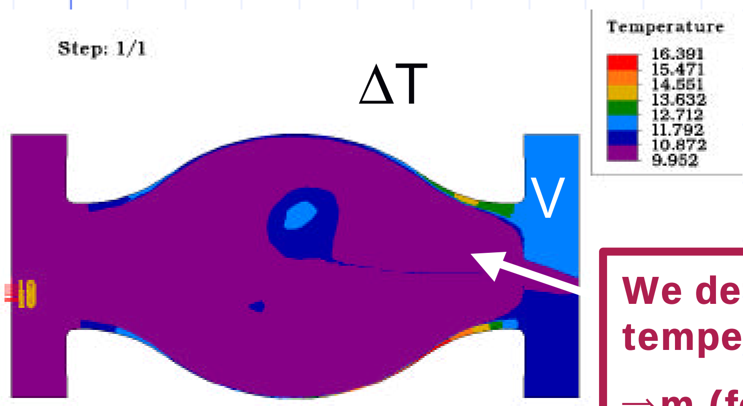
- **What is the mass flow needed to cool the beam?**

Simulation of the flow by Wing Lau/ Charles H. Holding (Oxford) using Algor 2 D model

- **How to use the results?**

Determine velocity so that $\Delta T < 1K$





We determine the velocity, V, for the addoc temperature difference, ΔT:

$\Rightarrow$m (for given ΔT, nozzle geometry and LH2 prop.)

$\Rightarrow \Delta P$(for LH_2 cryoloop)

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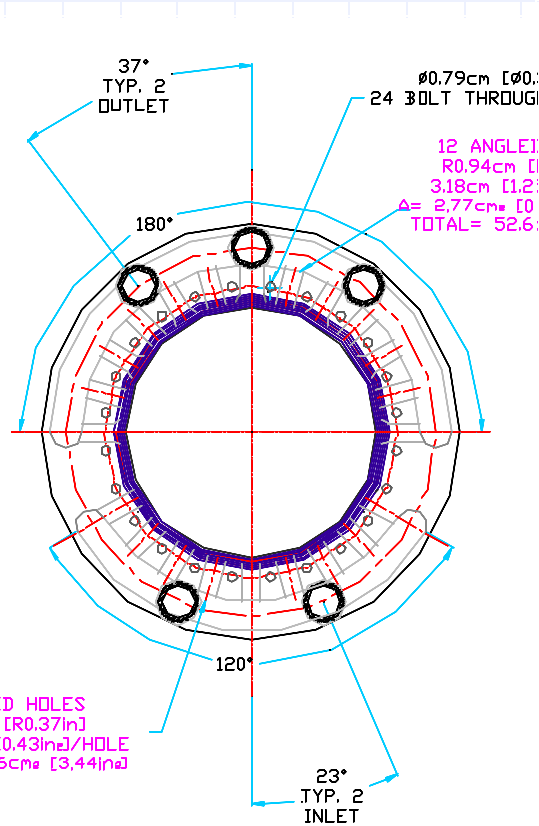
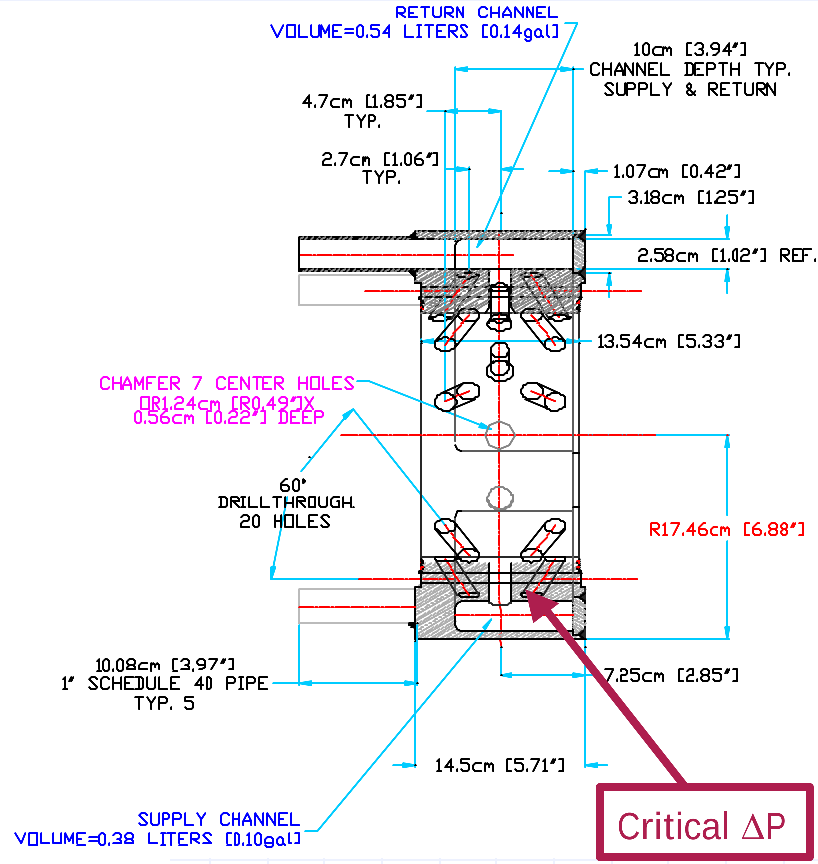
LH2 Manifold absorber (by E. Black)





Overview on the Absorber Pump flow method

Optimization of the pressure drop

If V=4 m/s then m=450 g/s with new geometry

LH2 abs:	**LH2 abs:**
Nozzle dia.= 0.6”	Nozzle dia.= 0.43”
8 Supply nozzles	11 Supply nozzles
12 returns nozzles	15 returns nozzles
Piping in the magnet bore:	**Piping in the magnet bore:**
40 cm long IPS 1” pipes	20 cm long IPS 1” pipes
10 cm long IPS 2”pipe	30 cm long IPS 2”pipe

Status:

- **Geometry upgrade, temperature upgrade in Algor model**
- **Optimal flow regime determination**
- **Need to determine the minimum velocity for which $\Delta T=1$ K**
- **Influence of the nozzle number to reduce the hot spot=>3D model**
- **Influence of the beam distribution**